



Multiplexed Optical Scanner Technology (MOST)

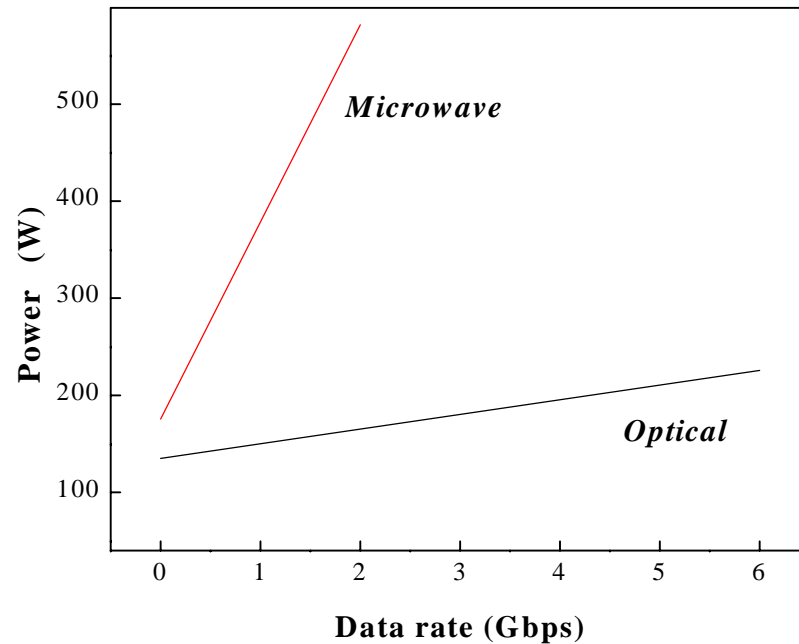
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Motivation

- To Develop Laser Beam Steering Technology for Military Applications :
 - Infrared Countermeasures (IRCM)
 - Target Designation
 - Laser Communication

Clear Advantage of a Free-Space Optical Wireless Link to an RF Wireless Link

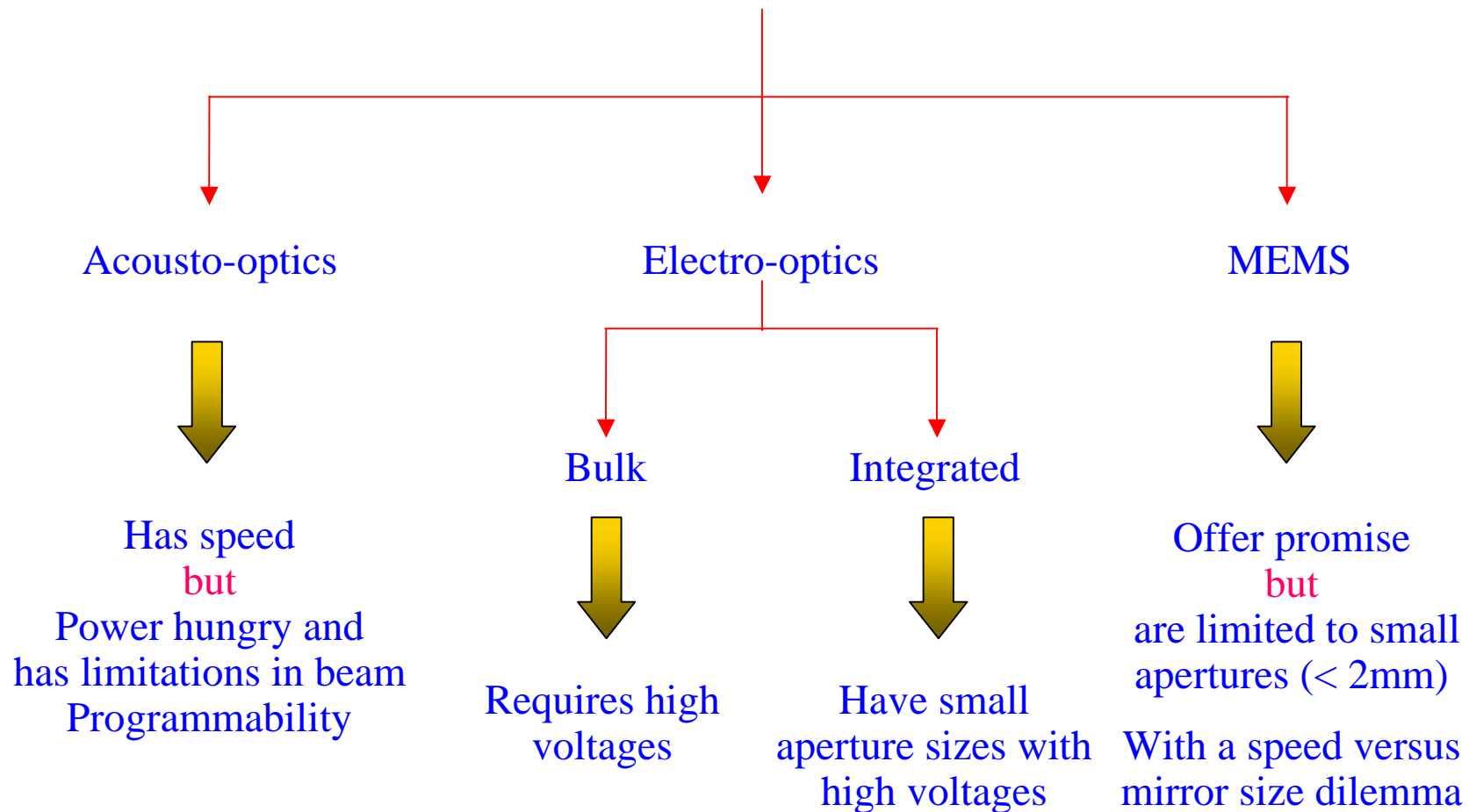


- Much Lower Power Consumption
- Smaller Antenna Size
- Higher Antenna Gain
- Much Smaller Beamwidth

	Optical	Microwave
Wavelength	1.55 μm	0.6 – 1.1 cm
Antenna diameter	0.1 – 0.25 m	1 – 2 m
Antenna gain	106 dB	50 dB
Beamwidth	5 μrads	5000-7000 μrads

Ref: F. R. Gfeller and U. Bapst, *Proc. IEEE*, Vol. 67, pp. 1474-1486, 1979.

Dominant Optical Scanner Technologies



Nematic Liquid Crystal (NLC) Based Scanner

- NLC-based Optical Scanners are Perhaps the Most Successful Optical Scanners Introduced So Far
- They Use Large Area Glasses, Birefringent Thin Films, and Electrically Programmed Phase Plates to Realize the Optical Scanner
- Satisfy All but One Requirement, i.e., Fast Speed
- Material Improvements May Resolve the Speed Issue

Can we Compromise?



YES!



Multiplexing

Multiplexed Optical Scanner Technology (MOST)

- Using NLC Design Philosophy, We have Introduced a Novel Optical Scanning Technology called “MOST”

- We Independently Exploit

- Polarization	P-MOS
- Time	T-MOS
- Wavelength	W-MOS
- Space	S-MOS
- Optical Code Switching	C-MOS

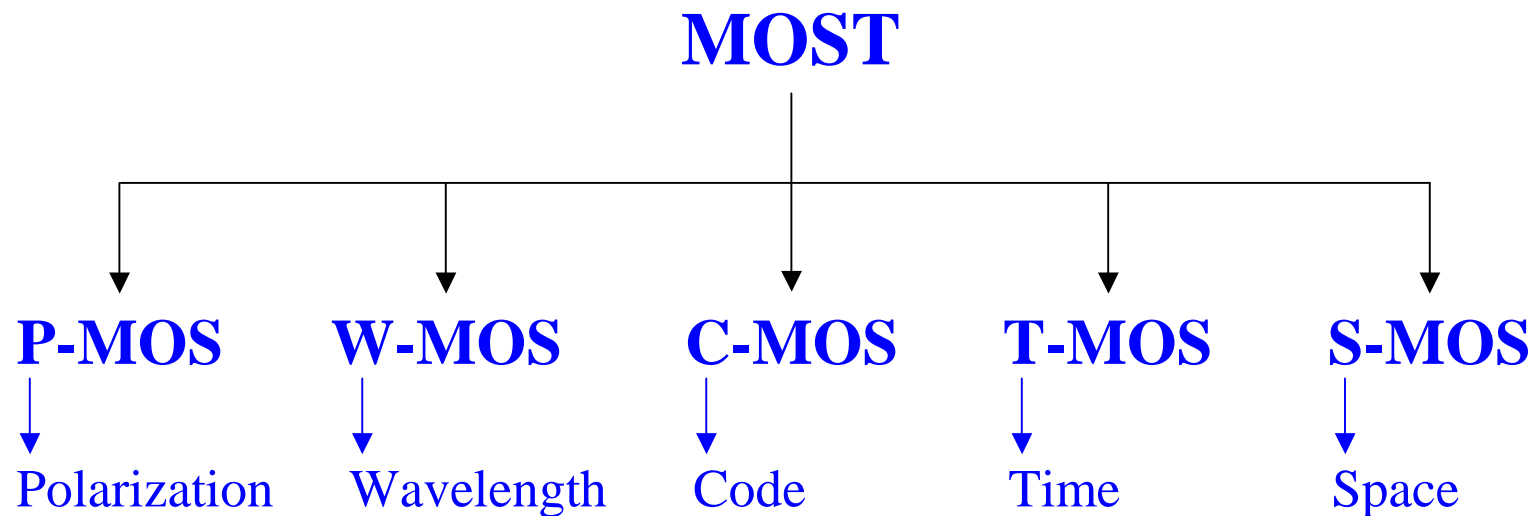
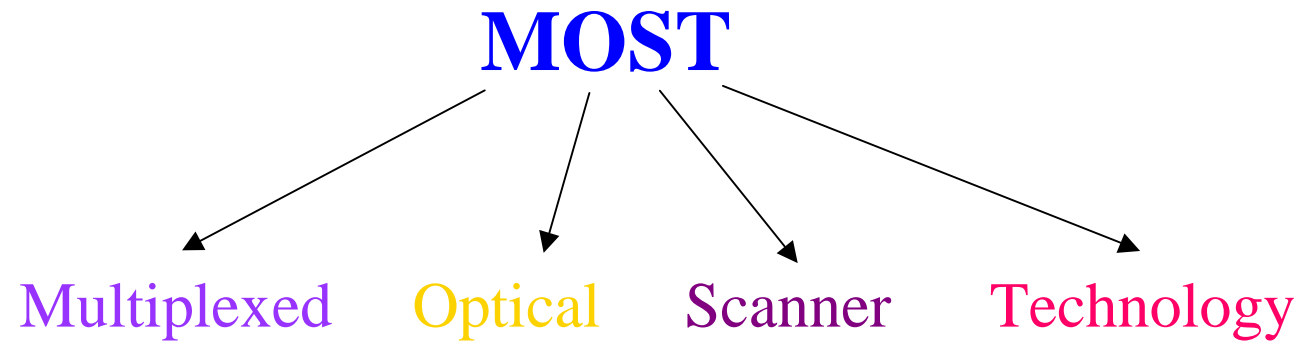
to Access 3D Phase Perturbations Stored in a Large Area, Fixed Phase

Sensitive Photo-thermal Refractive (PTR) Glasses or Programmable NLC

Devices to Realize High Speed Optical Scanners

Innovative Claims for the Proposed MOST

- Small & Lightweight
- Low Power Consumption
- Low Cost
- Rapidly (e.g., a few μ s or less) Configured
- Multiple Simultaneous Beams in Space
- Eye Safe Operation
- Wide Scan Angles (e.g., $\pm 45^\circ$)
- Large Apertures (e.g., 10 cm diameter) to Provide High Resolution Scans
- True Rapid 3D Beamforming Capabilities



P-MOS

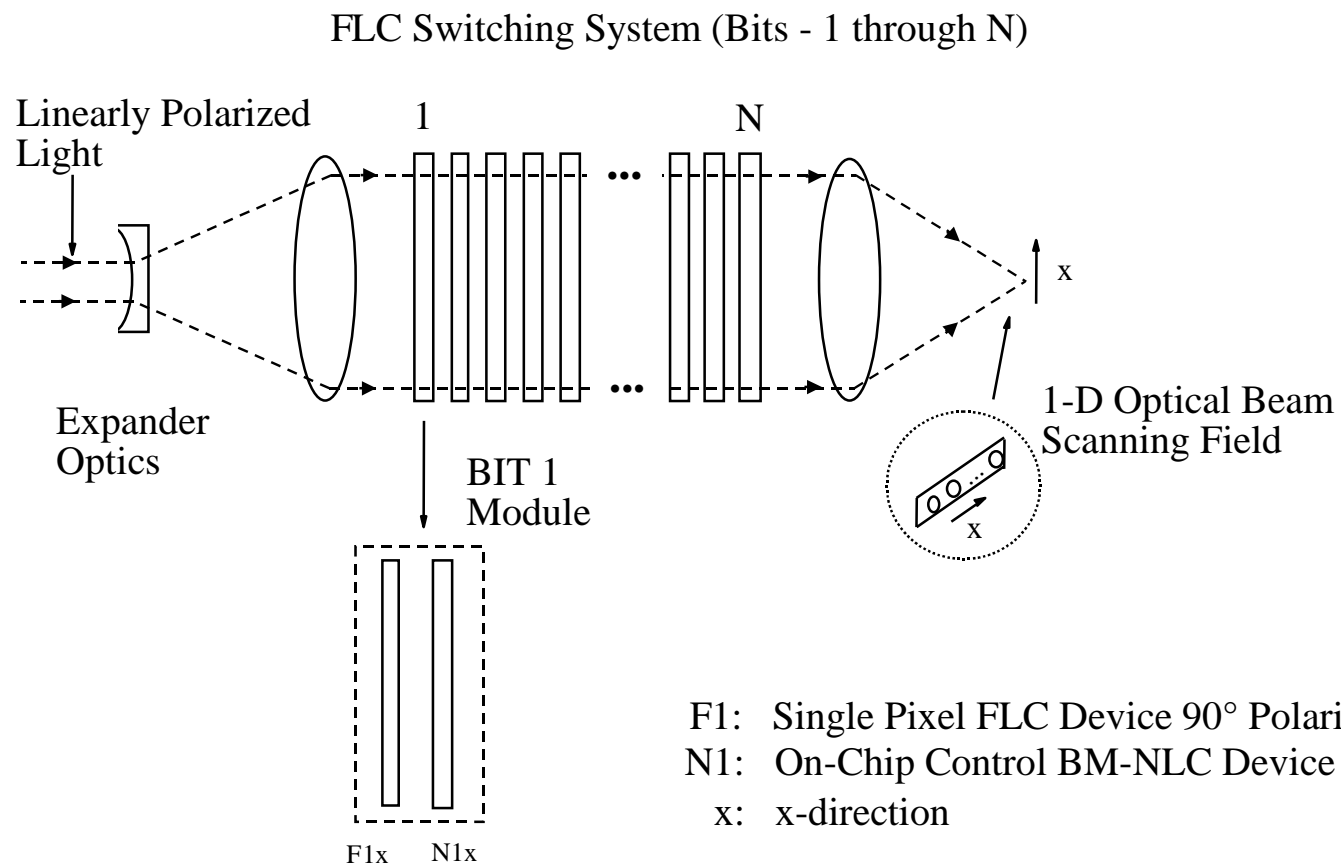


Polarization

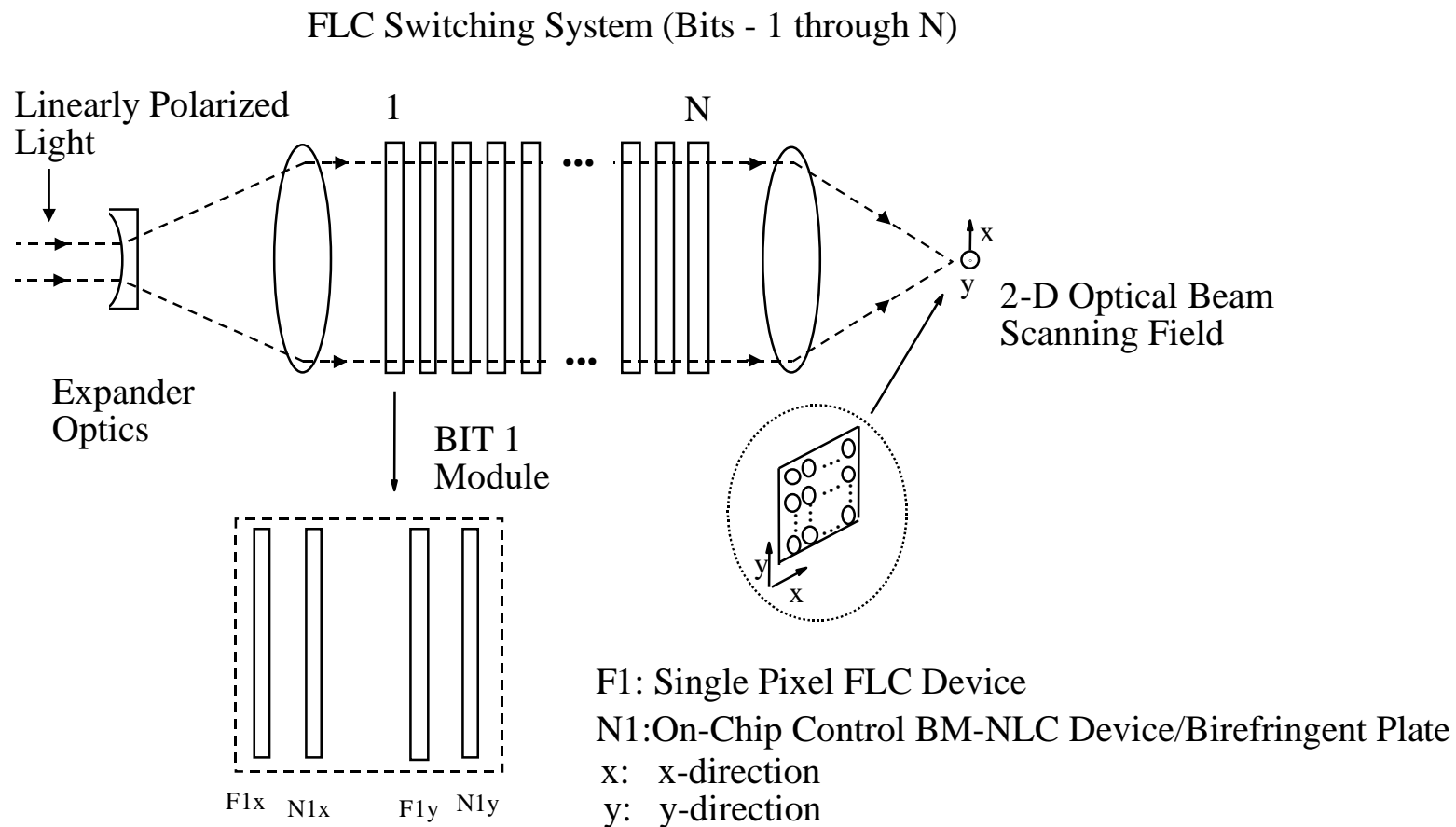
Principles of the Novel Scanner Design

- Binary Switched Design to Realize High Space Bandwidth Products (SBWPs) using minimum hardware
- Separation of Scan Dimensions for independent optical beamforming
- Use of high speed (microsecond domain) flat-panel thin film polarization switches (e.g., Ferroelectric Liquid Crystal Devices)
- Use of passive or slowly programmable, high efficiency, high resolution, optically birefringent plates for high accuracy optical wavefront control
- LEGOTM Style Stacking Structure for Interface with Other Scanner Technologies

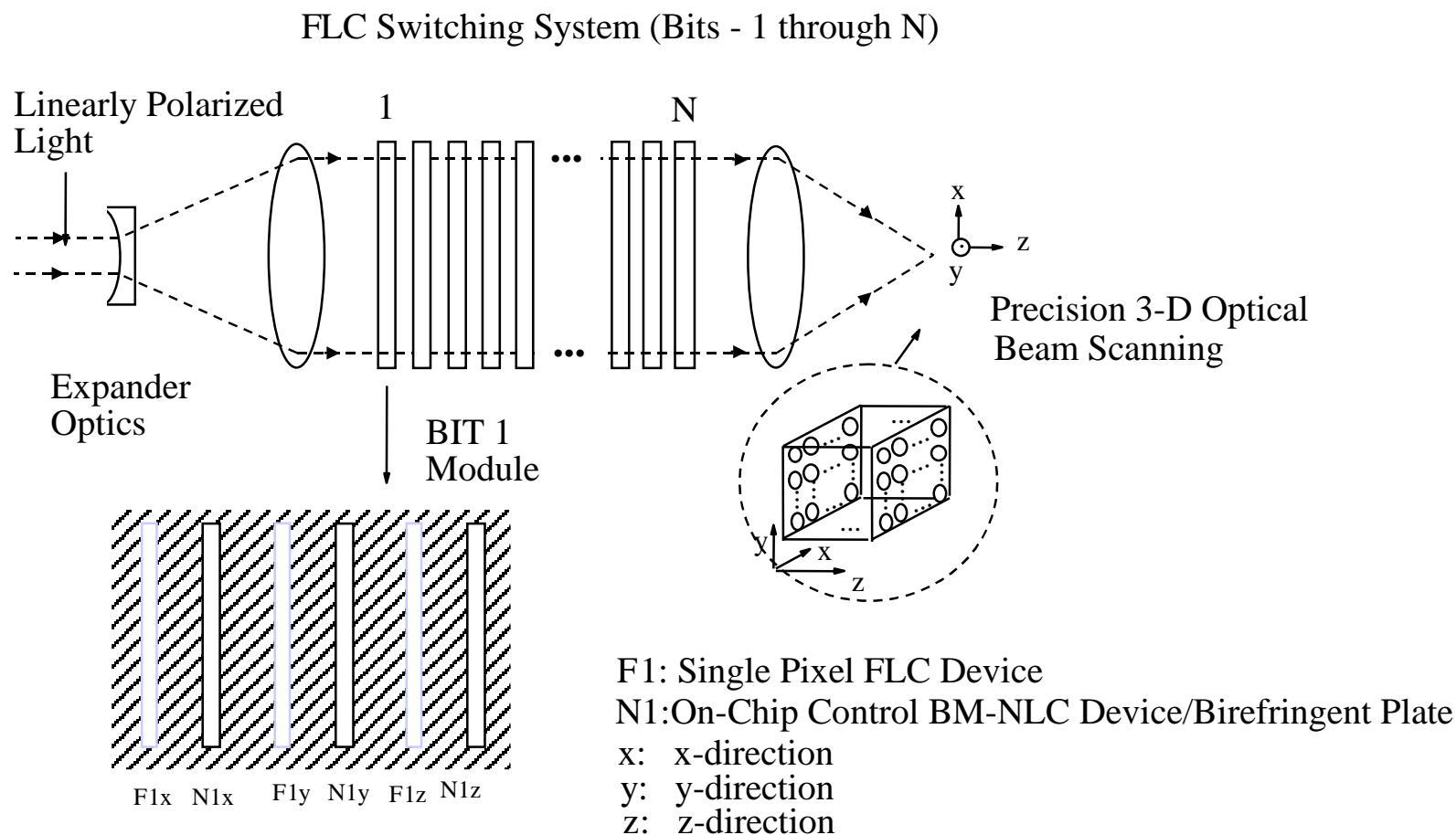
1-D Point Scanner (2^N Points)



2-D Point Scanner ($2^N \times 2^N$ Points)

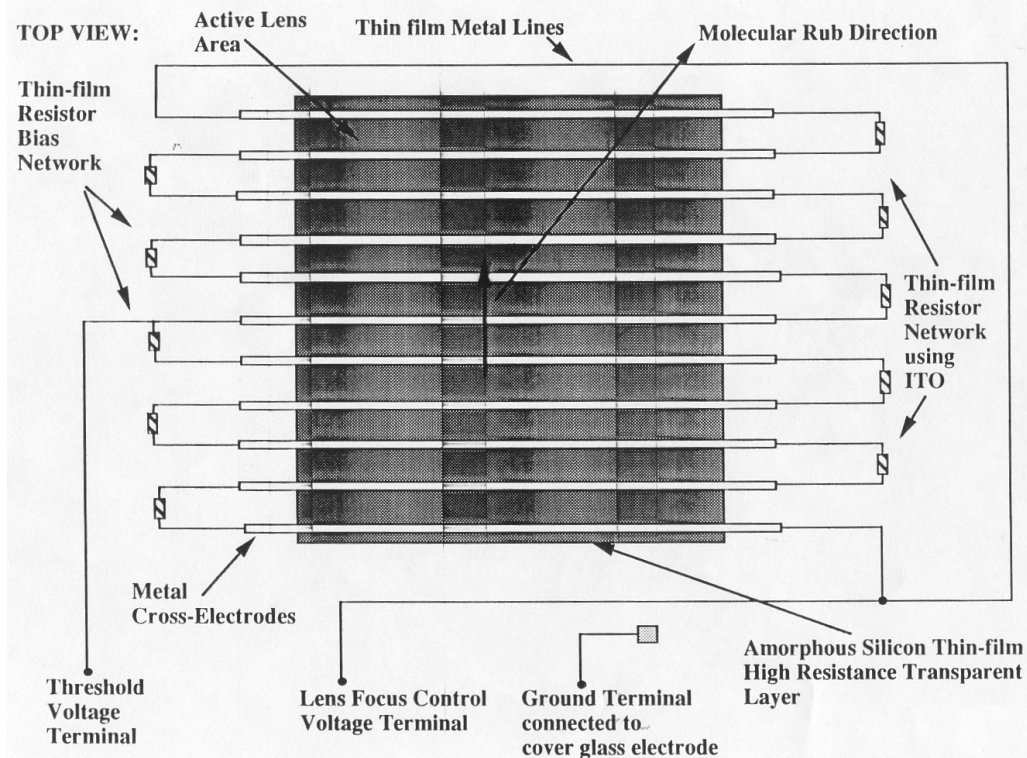


3-D Point Scanner ($2^N \times 2^N \times 2^N$ Points)



Note: Specific Order of Devices can be different from what shown to optimize application.

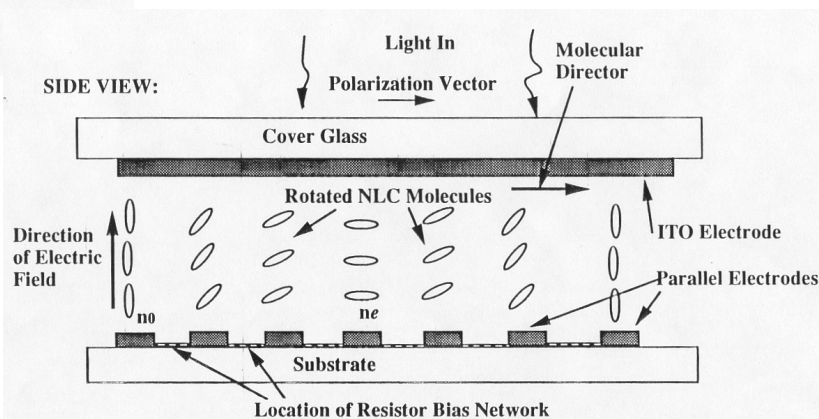
On-Chip Smart Control Liquid Crystal Devices



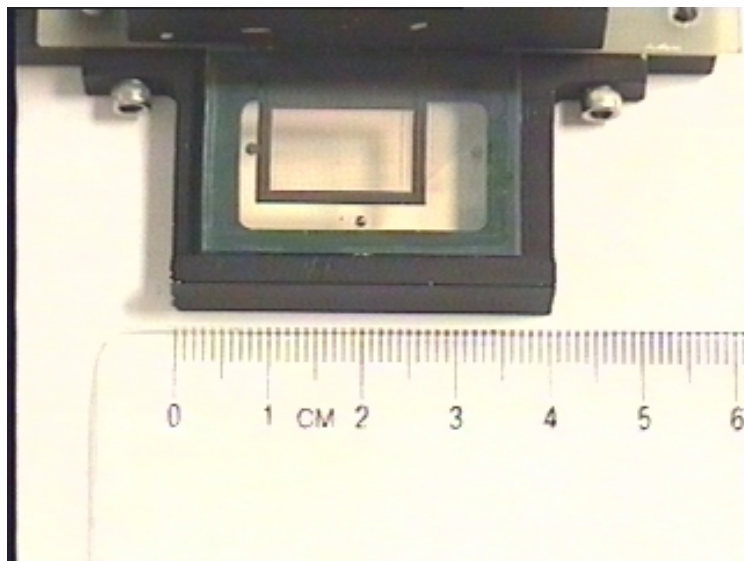
TOP VIEW

- Uses Only 3 External Terminals

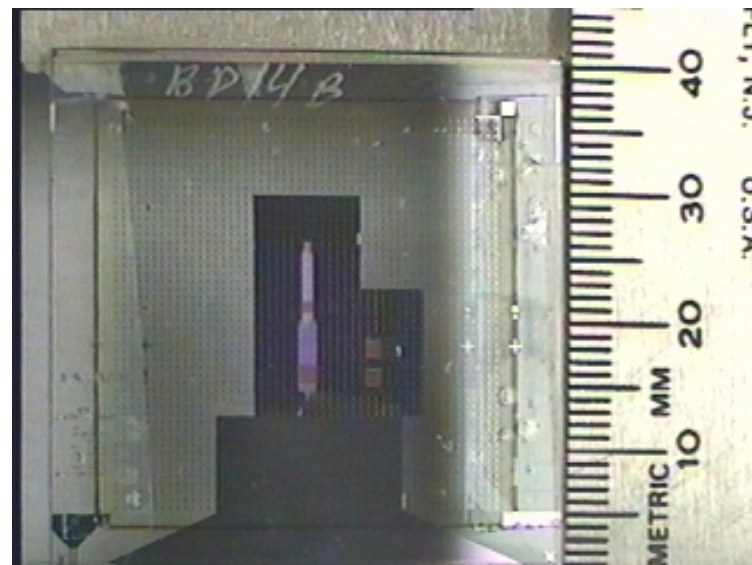
SIDE VIEW



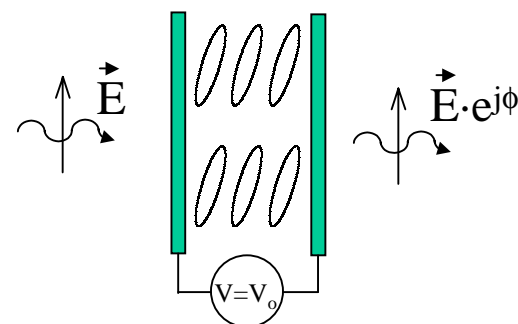
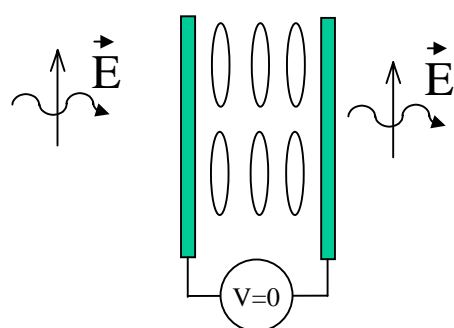
Birefringent Mode Nematic Liquid Crystal (BM-NLC) Devices



1500-pixel NLC Device



3-Terminal NLC Lens Device



Features of the Proposed Novel Digital Scanner Technology

- High Speed Inertialess Scanning., e.g., < 10 microsec Random Access Beam Reset time at 1320 nm
- Graceful Optical Loss vs. Scanner Power Tradeoff (e.g., < 1 dB/3-D bit)
- Cascadeable to Polarization-based Analog Optical Scanners such as a Birefringent-Mode Nematic Liquid Crystal (BM-NLC) device for Additional High Accuracy Beam Control
- Low System Control Power (e.g., Electrical Power in milliwatts)
- Ultra High Space Bandwidth Product Systems Possible
 - 1-D: e.g., 1000 pts.
 - 2-D: e.g., 1000×1000 pts.
 - 3-D: e.g., $1000 \times 1000 \times 1000$ pts = 1 Billion pts.
- Plug-In/Plug-Out Programmable Beamforming Optics using Birefringent Plates e.g., BM-NLC devices, diffractive optical elements (DOEs), polymer dispersed liquid crystals (PDLCs)
- Planar device technology allows extensions to parallel/multichannel scanner designs

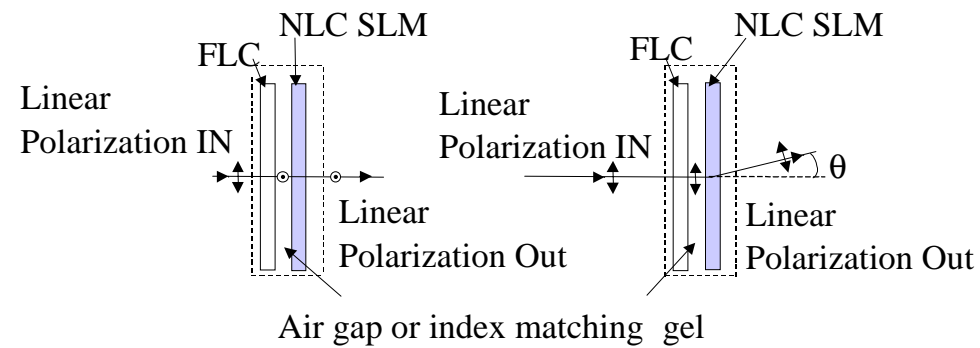
T-MOS



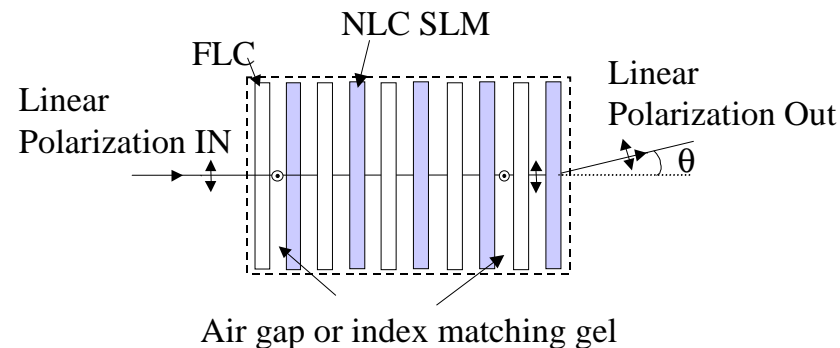
Time

Time Multiplexed Optical Scanner (T-MOS)

- Completely Programmable Single Bit T-MOS Structure



- Completely Programmable 5-Bit T-MOS Structure



T-MOS: Fully Adaptable Large Space Bandwidth Product Digital Scanner

- T-MOS is Similar to P-MOS in the N-bit Architecture
- Complete Electronic Programmability is Achieved by Using Birefringent (BR) phase-only SLMs such as NLC SLM
- During Operation, the Binary Polarization Switches are Set so that Input Light Beam Reads the Programmed Phase Information from one of the SLMs
- Thus, if it Takes T seconds to Program one SLM with a desired Phase Information, a T-MOS using N SLMs will Reset a Beam in T/N seconds
- T-MOS Provides a Mature Solution to the Speed problem that Otherwise Plagues BM-NLC SLM-based Optical Scanners

C-MOS

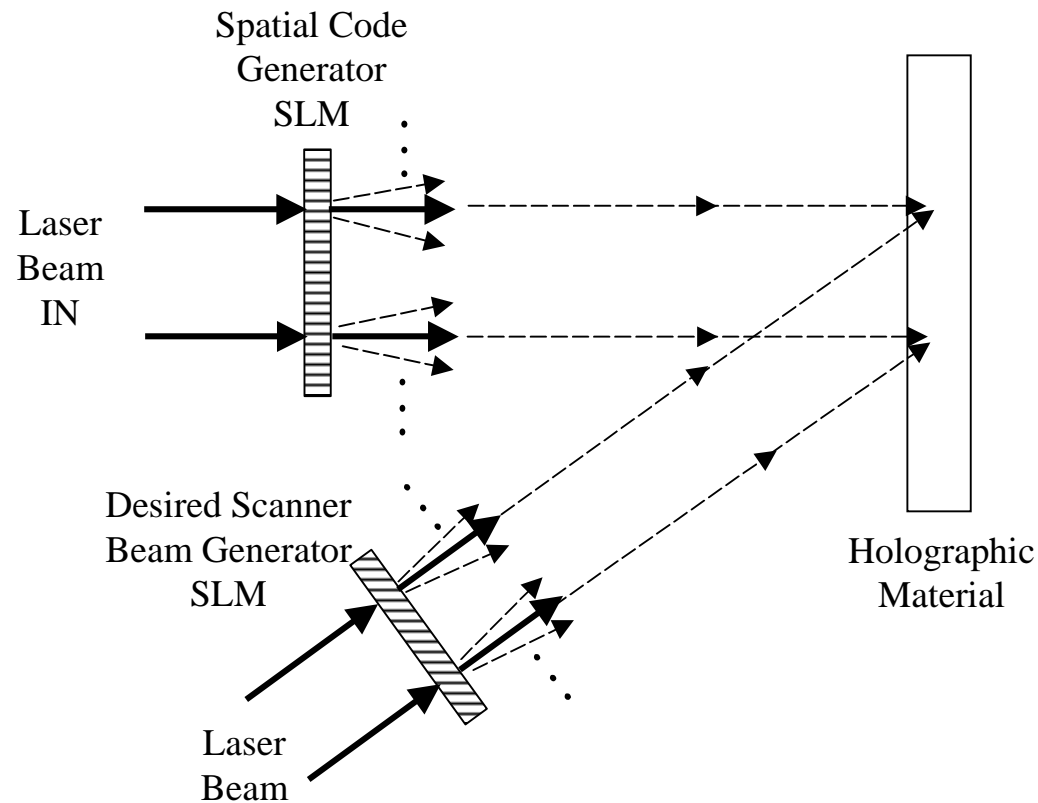


Code

C-MOS: Code-Multiplexed Optical Scanner

Principle: Holography

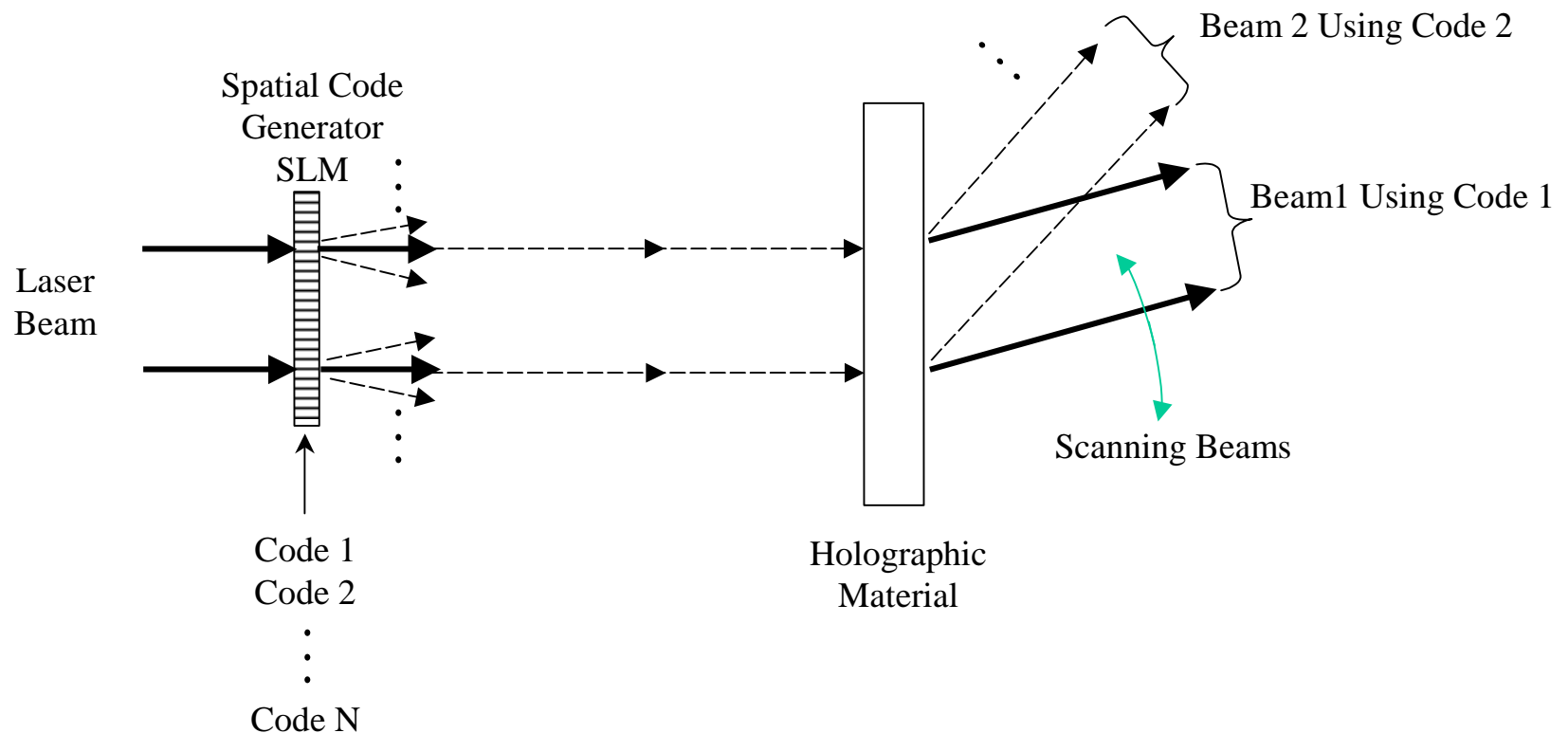
Recording



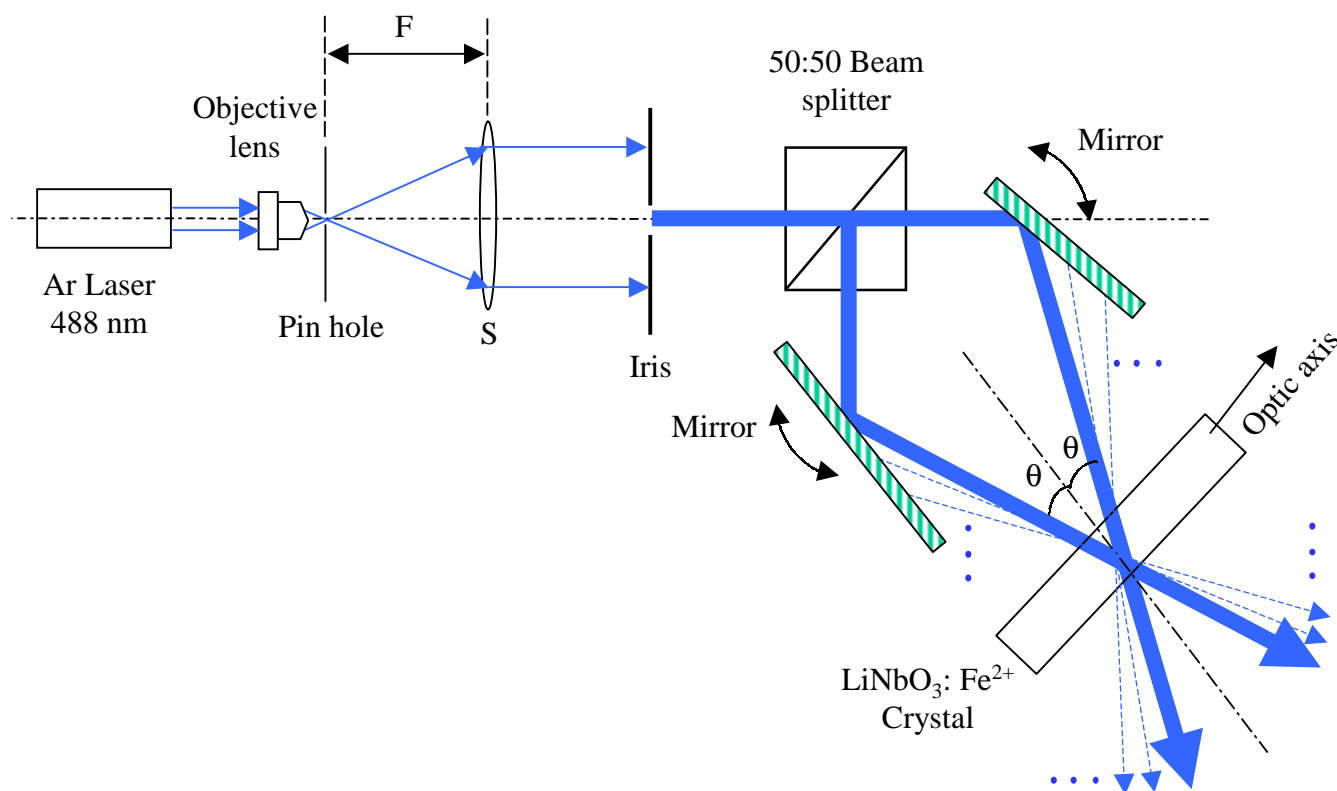
SLM: Spatial Light Modulator

C-MOS: Code-Multiplexed Optical Scanner

Readout

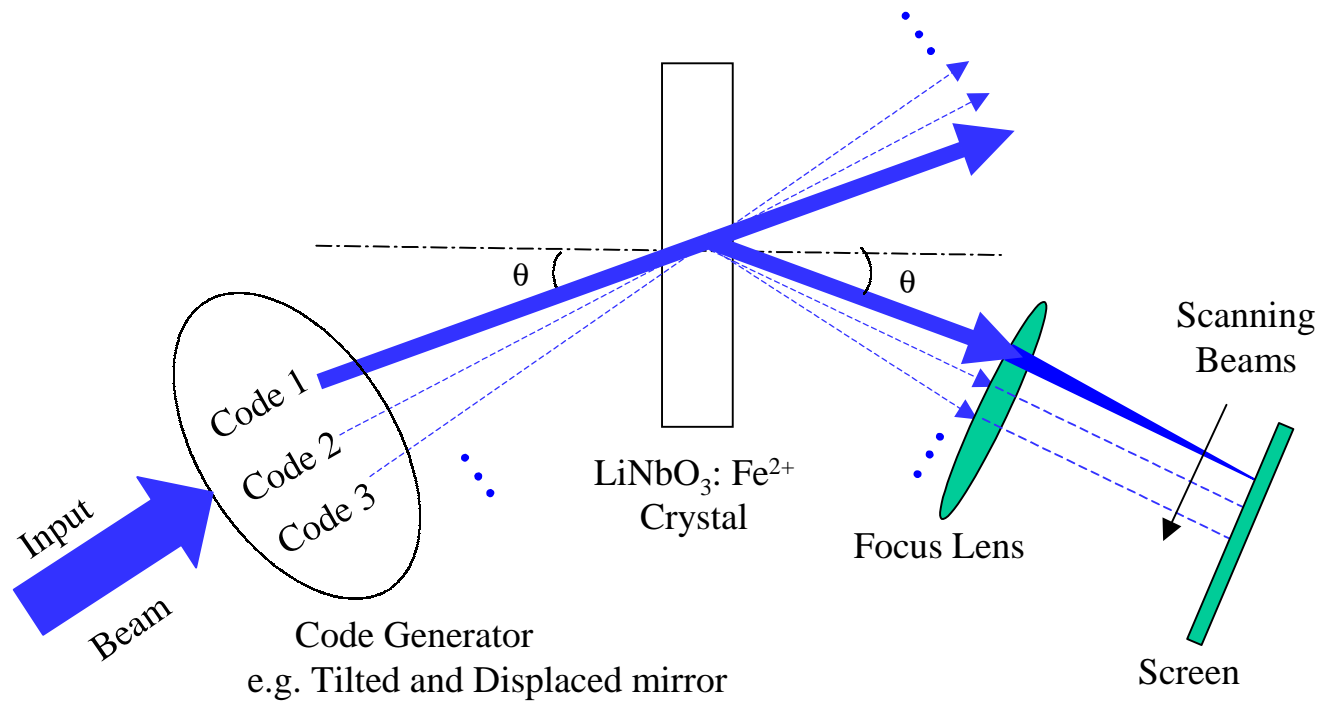


Experimental Setup for Hologram Recording



S: Spherical Lens with a F focal length

Readout of Hologram Recording

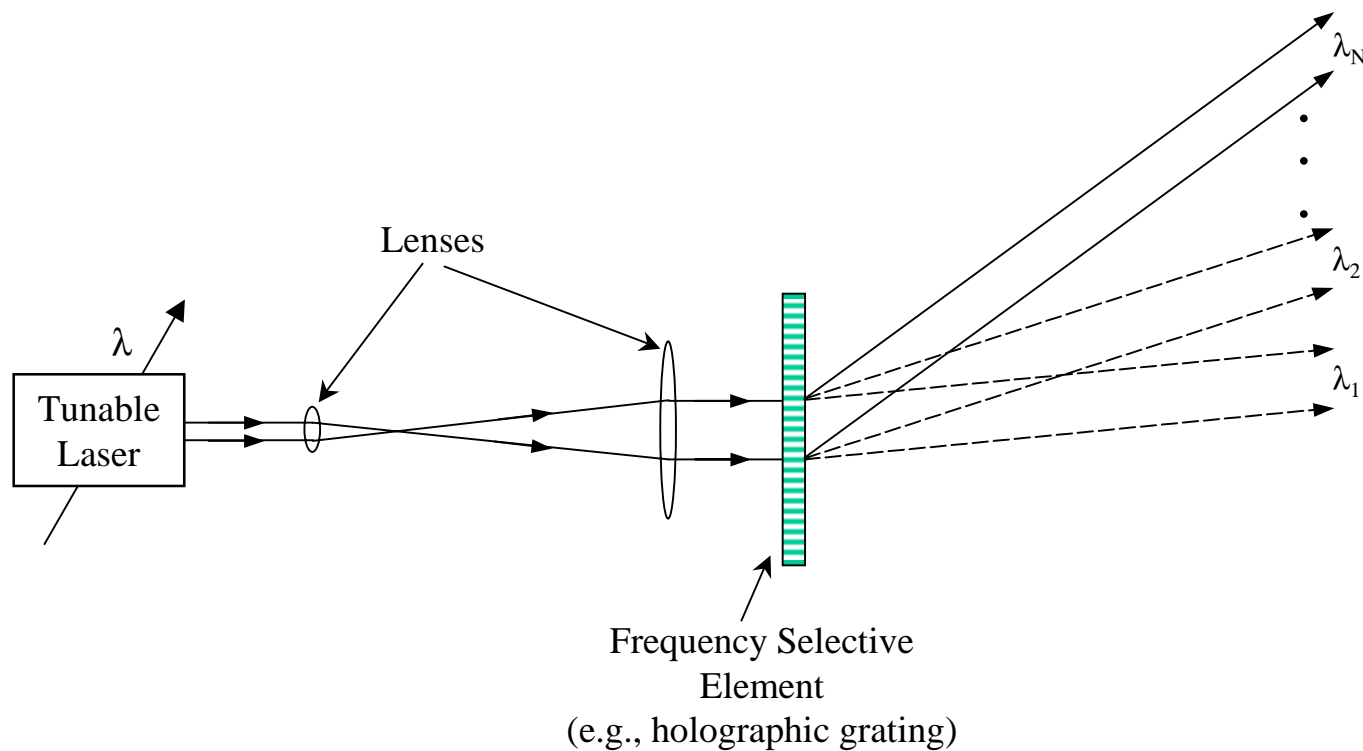


W-MOS

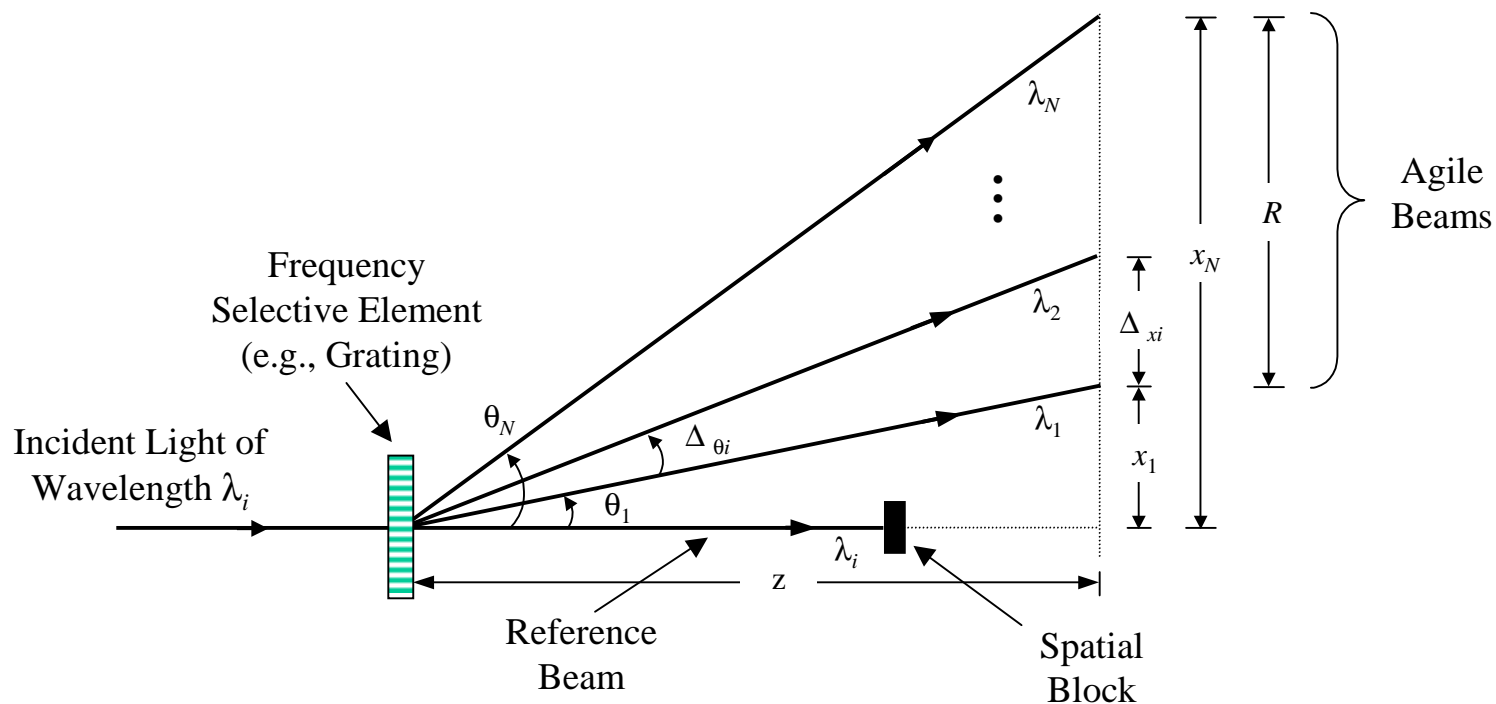


Wavelength

Free Space Version of W-MOS



Free Space W-MOS Concept



For normal incidence, the grating equation for the 1st order beam is given by*:

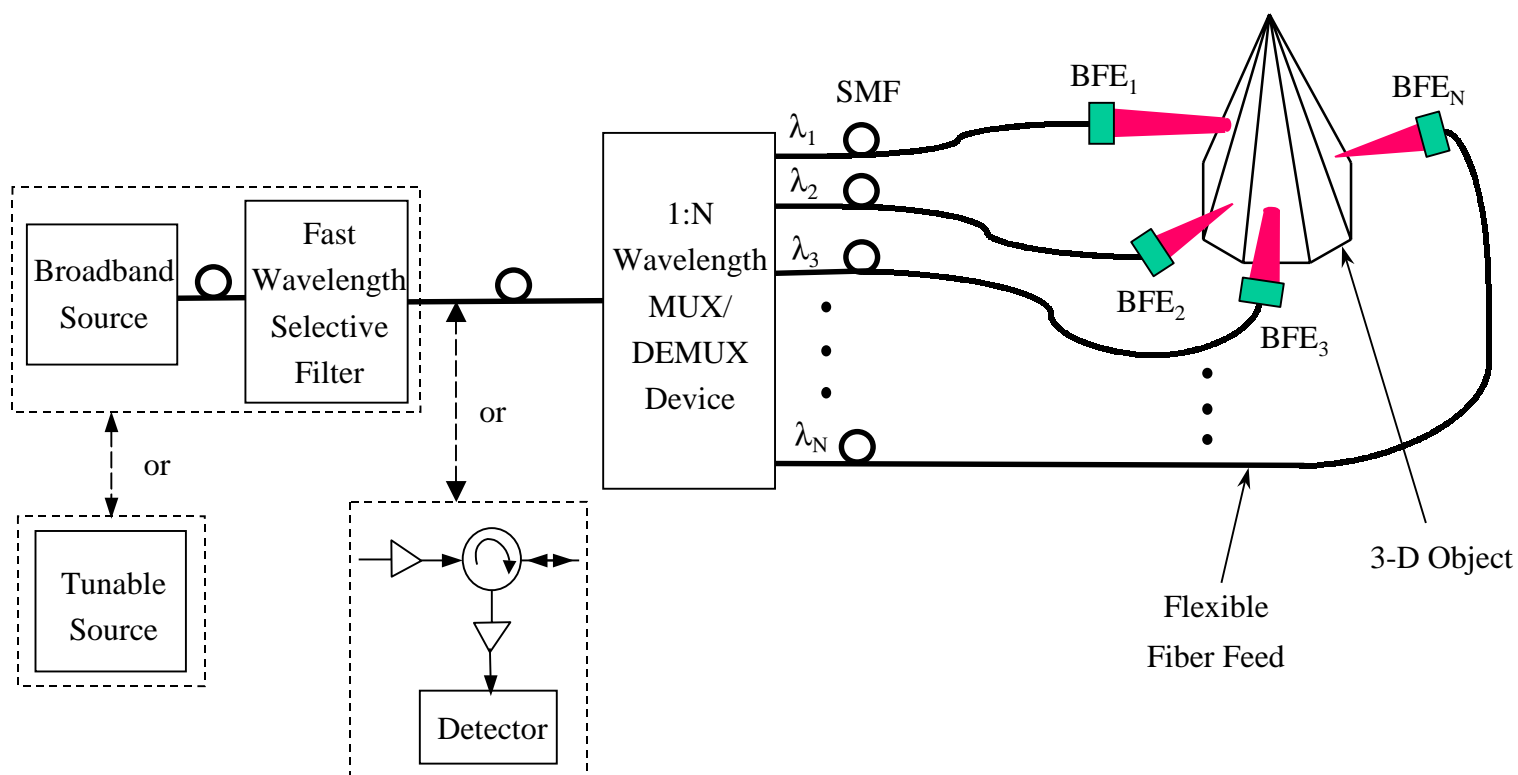
$$\sin \theta_i = \frac{\lambda_i}{L}$$

L : Grating period

θ_i : Diffraction angle for the λ_i optical beam

* C. Palmer, *Diffraction Grating Handbook*, 3rd Ed., Richardson Grating Laboratory, 1996.

Our Proposed Three-Dimensional Fiber Remoted W-MOS



—▷: Optical Amplifier

↻: Circulator for Acquisition Mode

SMF: Single mode fiber

BEF: Beamforming element

Options for the Fiber-Connectorized Wavelength Selective Element

Multiplexers/Demultiplexers -- based on:

- Fiber Bragg Gratings
- Wavelength Selective Holograms
- Micromachined Fabry-Perot Filters
- Interference Filters
- Array-Waveguide Gratings (AWGs), e.g., 128 channels.

Features of the W-MOS

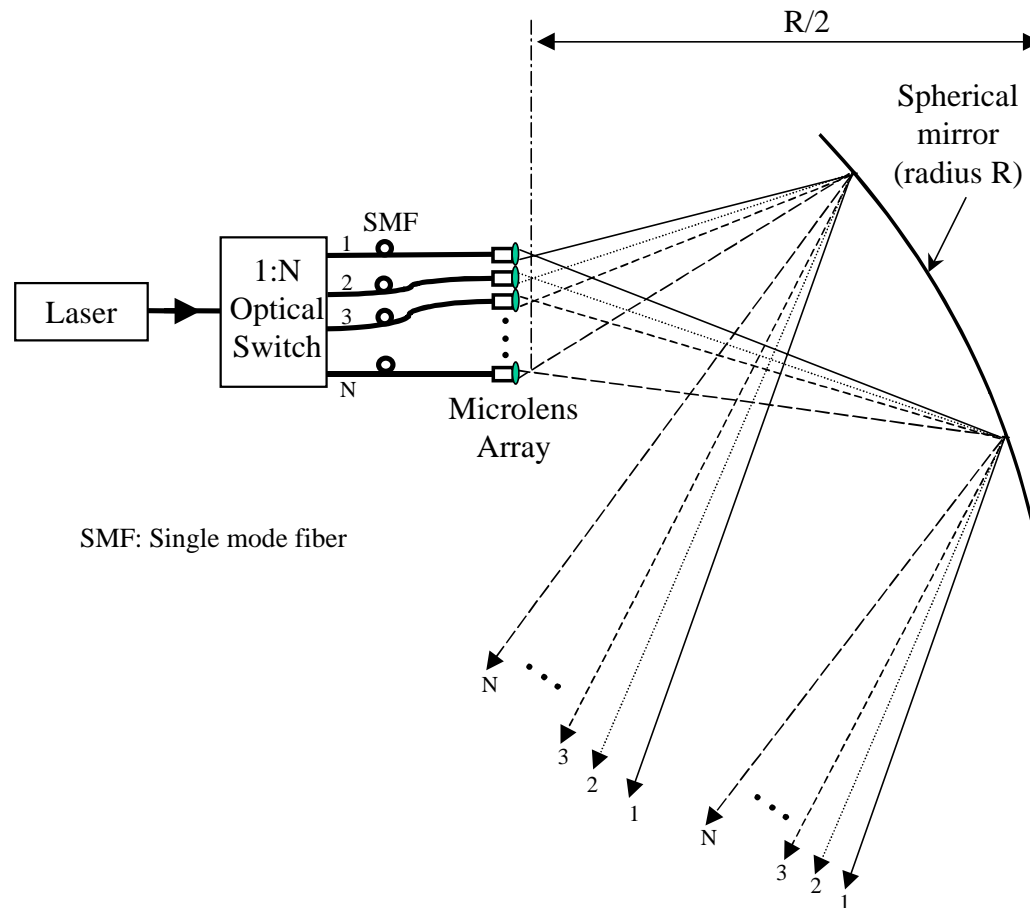
- Simple Optical Design
- Large Field of View (e.g., up to 360°)
- Ability to Scan Large Volumes and Complicated 3-D Geometries
- Simple Control (via Wavelength Tuning)
- Simultaneous Multi-Beam Generation (using multi- λ drive)
- Ultra-High Speed Beam Scanning Options (e.g., 1 ns)
- Low Loss Designs
- Low Cross Talk

S-MOS



Space

Space Multiplexed Optical Scanner (S-MOS)



S-MOS: An Extension of the W-MOS

- S-MOS can be Considered as a Special Case of the W-MOS
- The Tunable Laser has been Replaced by a Single Wavelength Laser
Connected to a 1xN Optical Space Switch that Further Feeds a Conformal
Fiber Array
- The Positions of the Fiber/Microlens Output Planes are Designed to
Generate a 3D Beam Control Operation after Reflection from a Large
Mirror
- S-MOS Doesn't Require Wavelength Tuning, Although Tuning Can be
Exploited for Security Purposes

Comparison of the Key MOS Technologies

MOS Type	3-D Beamforming	Beam Control Architecture	Beam Switching Speed	Key Features
P-MOS	Access fixed phase data	Digital N-bit Binary Switched	Fast (μs)	Very high beam count (e.g., > 100,000) with simple binary scanner control
T-MOS	Access continuously programmed phase data	Digital N-bit Binary Switched	N times faster than a single programmable phase device	Complete beam programmability & adaptability, very high beam count (e.g., > 100,000)
W-MOS	Access fixed phase data	Single Stage parallel	Very fast (ns)	Ultrafast scanning; Wide 360° coverage fiber-option, covert signal transmission
C-MOS	Access fixed phase data	Single Stage parallel	Moderate (tens of μs)	Ultra-compact design, High beam count (e.g., > 50,000)

General Advantages of MOST

MOST Provides the Following Features Compared to Other Technologies :

- Large Apertures (e.g., > 10 cm)
- Planar Stacked Design of both Active and Passive Optics Leading to
Compact Lightweight, highly Manufacturable Devices
- Low Cost Design Using Large Area Glasses for Encapsulation of LCs and
Holographic Devices
- Low (e.g., mW level) Electrical Power Consumption due to Thin Film
Nature of Active Devices
- Built-in Optimum Beam Shape and Direction Features by Appropriately
Designing the Optical data in the Storage Components

General Advantages of MOST (contd...)

- Large Number of Scanner Beams Can be Efficiently Implemented using the Various Multiplexing Options
- Fast Reconfiguration Speed Options all the Way from Tens of microsecond to Tens of nanosecond regime
- Multiple Simultaneous Beams can be Generated by Using Multiple Wavelengths in the W-MOS or Multi-Beam Phase Plates in the Other MOSs
- Multiple Scanners, all Operating Spatially in Parallel, Can be Fabricated in a Single Module, as Glass Plates can be Etched with Multiple Pixels

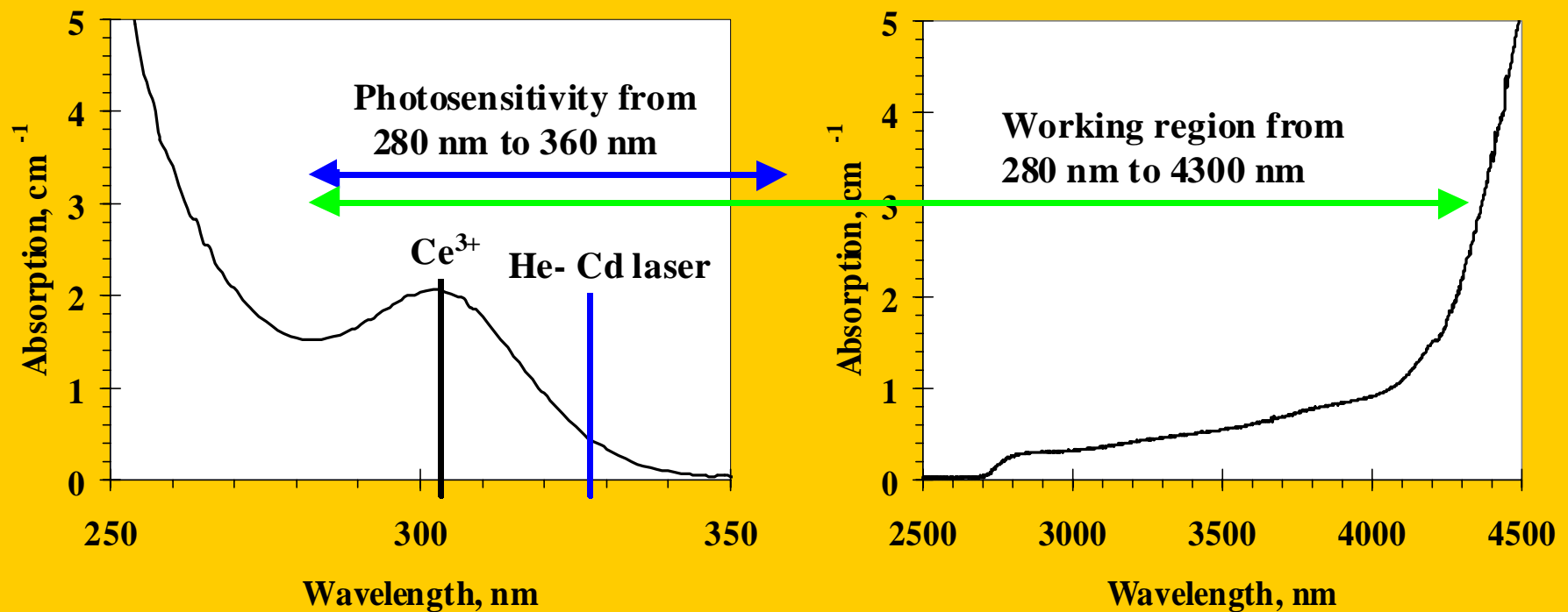


UCF

CREOL

Photo-Thermo-Refractive Glass

This material possesses the same chemical, mechanical, and thermal durability as silicate glass does, and is transparent in the UV, visible, and IR regions from 0.28 μm to 4.3 μm . PTR glass is very photosensitive, requiring a few hundred mJ/cm^2 in the spectral region from 0.28 μm to 0.36 μm . Laser damage threshold of exposed and developed glass in the nanosecond regime is more than $10 \text{ J}/\text{cm}^2$.

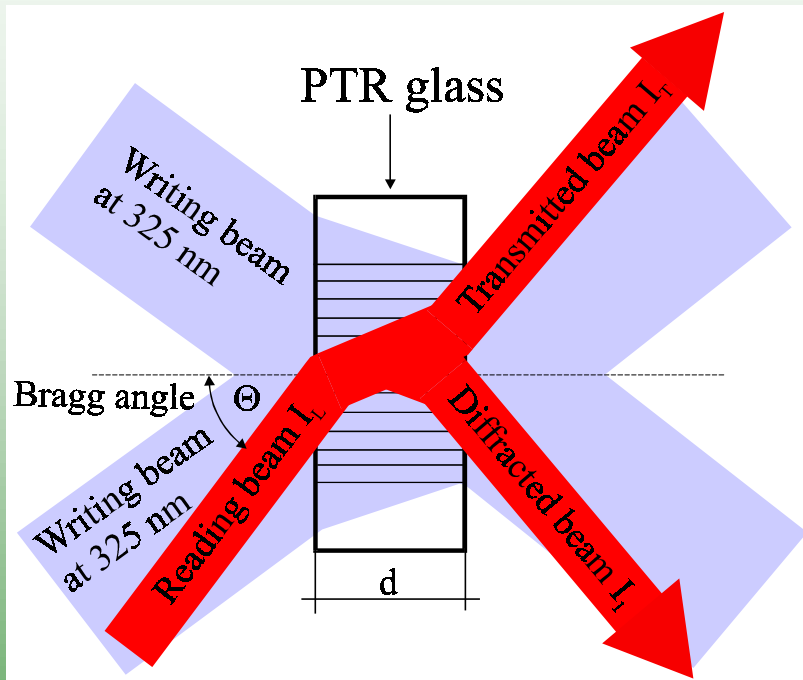




UCF

CREOL

Transmitting Bragg Gratings

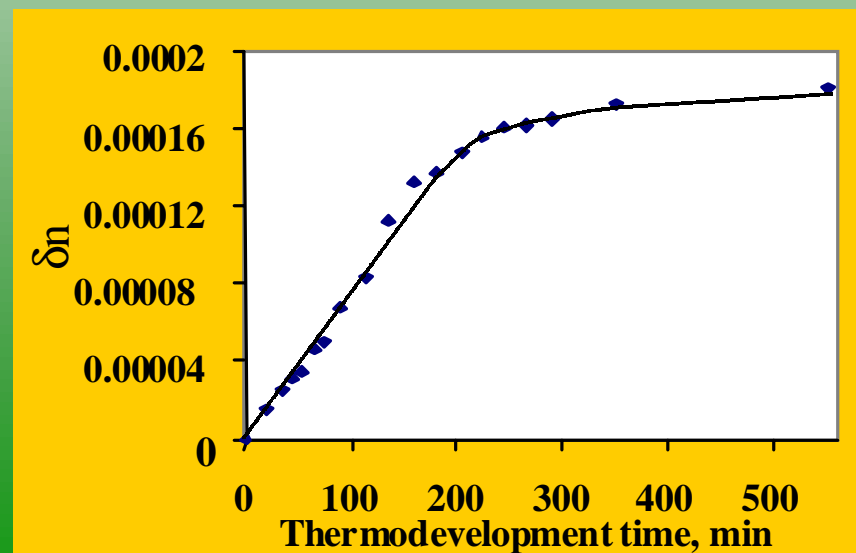
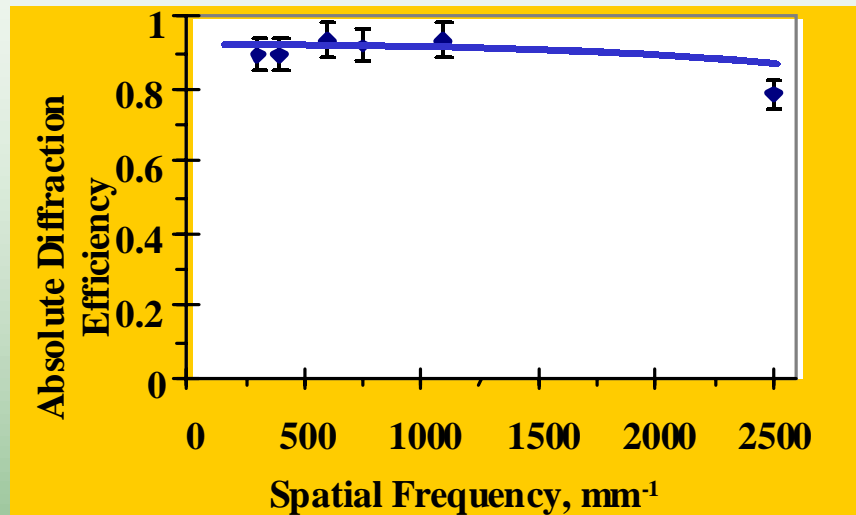


$$\eta_A = \frac{I_1}{(1 - \rho)^2 I_L}, \quad \eta_R = \frac{I_1}{I_1 + I_T}$$

$$\delta n = \frac{\arcsin(\sqrt{\eta_R}) \lambda \cos \Theta}{\pi d}$$

η_A and η_R - absolute and relative diffraction efficiency

ρ - reflection coefficient, λ - wavelength





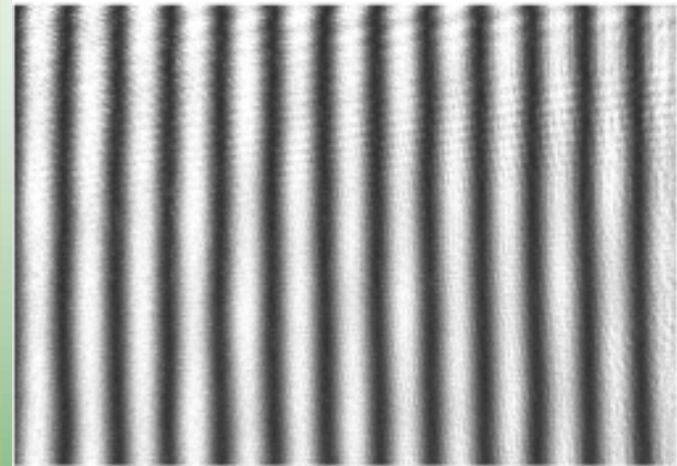
UCF

CREOL

CREOL-Fabricated Holographic Gratings in PTR glasses State-of-the-Art

Glass Fabrication and Characterization

- Technology of melting homogeneous PTR glasses in 400 cm³ crucibles has been developed. Refractive index variations in as-melted glass are below 10⁻⁵ in 1 cm² specimen (see interferogram).
- Technology line for grinding, polishing, and thermal development has been established.
- Optical homogeneity and induced refraction testing setup with sensitivity 10⁻⁷ has been developed.



Bragg Gratings Fabrication and Characterization

- Writing laser He-Cd, 325 nm, 1 mW
- Exposures from 50 to 2500 mJ/cm²
- Writing beam diameter up to 5 mm
- Thickness of volume gratings from 0.2 to 5 mm
- Absolute diffraction efficiency up to 93 %
- Angular selectivity down to 0.2 mrad
- Spatial frequency up to 10,000 mm⁻¹ (100 nm period)
- Mirror for $\lambda=325$ nm with $\Delta\lambda<0.1$ nm and $R>12$ %
- Writing of up to 20 individually- readable gratings in the same volume of specimen

Steered Agile Beam (STAB) DARPA MOST Program

- Duration: 4 years
- Objective: Match Two Critical Military Applications with the Best MOST

Options e.g., Laser radar & Laser Communication

- Research Plan:
 - Study All MOS Features & Limitations
 - Design and Conduct Proof of Concept Experiments
 - Optimized Application Demonstrations with Two Lab. Test Beds